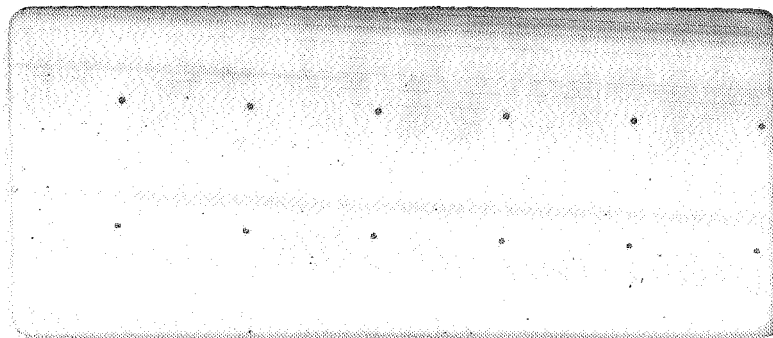


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JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

INTERIM REPORT OF
NASA WORKING GROUP ON
SURVEYOR LANDING AIDS FOR APOLLO

EPD 298, Rev 1

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SECTION I

INTRODUCTION

Within the next several years Surveyor spacecraft will be soft-landing on the lunar surface. These landed spacecraft will measure surface characteristics and, by means of movable television cameras, perform a survey of the area within the line of sight of these cameras. Some time after the first successfully landed unmanned Surveyor spacecraft, Project Apollo will be attempting a manned lunar landing. Therefore, it is desirable that Surveyors be landed in potential Apollo landing sites and be designed to evaluate the suitability of that landing site, and have a landing aid on board to guide the first astronauts to the particular site which will be best known at that time.

The NASA Working Group on Surveyor Landing Aids for Apollo was chartered on February 5, 1965, and has examined various possible devices which might be transported by a Surveyor spacecraft and which might be used by a Lunar Excursion Module (LEM) during its descent phase or by a Command Service Module (CSM) while in lunar orbit. At this time, active and passive RF as well as visual devices have been investigated. The tentative results to date are presented in this document. Recommendations for further activity leading to the construction of flight qualified equipment which may be used on scheduled Surveyor spacecraft are given in Section VI.

SECTION II

SPACECRAFT DESCRIPTION

In this section, the pertinent mechanical and operational aspects of the Surveyor and Apollo spacecraft are discussed. More detailed descriptions may be found in References 1 and 2.

A. SURVEYOR

The first four Surveyors, the engineering missions, will demonstrate the basic design concept. They are characterized by an injected weight of 2200 lb and a payload weight of 62 lb and will not be able to survive one lunar night.

The next three Surveyors, the operational missions, will make measurements which will contribute new scientific knowledge about the Moon and support a subsequent Apollo landing. These spacecraft will be characterized by an injected weight of 2450 lb and a payload weight of 114 lb, and will probably not be able to survive one lunar night.

The follow-on Surveyors will be based on a minimum modification of the operational mission design. The injected weight will remain at 2450 lb while the payload weight may increase by 20 or 30 lb (the dry-landed weight would not increase, but the basic bus would be simplified, which would allow additional payload). Part of this payload could be devoted to a landing aid.

As discussed in the next two sections, there are two basic types of landing aid, as seen by a Surveyor spacecraft. The two types, defined by their interface with the landed spacecraft, are Surveyor-dependent and Surveyor-independent devices. The dependent types require that the spacecraft survive for an appreciable period of time. The independent types do not require the Surveyor to continue functioning after the spacecraft has landed and performed any required deployment.

B. APOLLO

The objective of the Apollo Project is to safely land astronauts on the surface of the Moon, where they can undertake an exploration of that environment and subsequently return to Earth. To take advantage of the knowledge about the area where a spacecraft has landed and performed some measurements, the LEM should be brought down close to the same spot. An extended site survey would make a given area more desirable, but the mere fact that an unmanned spacecraft had successfully soft-landed leads to a better evaluation of that site than of any other.

Even if LEM guidance were perfect, there would be some difficulty in landing near a Surveyor with no landing aid because the uncertainties in the lunar ephemeris, shape, and size would introduce errors larger than the desired landing accuracy (CEP of 100 ft with, and 3,000 ft without a landing aid). Reference 3 indicates the effects of the uncertainties listed above; Reference 4 indicates the expected results of tracking the Surveyor spacecraft after it has landed. The astronauts could guide the LEM close to the Surveyor if they were able to visually acquire it in sufficient time; but the Surveyor has a very small cross section and could not be seen until the astronauts were quite close unless it had some type of location aid to enhance its visibility (see Reference 5).

Though primarily a device to be used during the LEM descent phase, if the landing aid were detectable from orbit before initiation of LEM descent, this would be additionally useful information for homing-in to the desired site. Specifically, if the Surveyor location uncertainties were more than 500 m. (1σ), they could be reduced to that value. (Any capability of visual enhancement during lunar orbit could also be used by the lunar orbit to identify a landed Surveyor within the area photographed.)

A landing aid could be designed to be detected by either the LEM rendezvous radar or by the astronauts' visual perception. Perhaps such a device could be used both ways during various phases of the LEM descent in a more optimum manner than one which could be detected in only one mode.

SECTION III

DESCRIPTIONS OF SOME LANDING AIDS

Landing aids may be categorized as active or passive, RF or visual, Surveyor-dependent or -independent. A particular device may fall into several of these categories, or it may be of hybrid design.

Several studies regarding specific types of landing aids have been performed (see References 6, 7, 8, and 9). The devices studied are described in order of increasing complexity, which is essentially the order of increasing usefulness for LEM descent guidance. The next section considers the implications of each landing aid on the Surveyor mission.

A. VISUAL DEVICES

Various types of visual devices would be feasible, the primary requirement being that enough light be reflected toward the astronauts so that they can recognize it against the lunar background (see Reference 5). Such devices might be erectable diffuse or specular reflectors. A specular reflector might be arranged in a symmetrical configuration or might require orientation to concentrate the reflected energy in preferred directions.

B. PASSIVE RF DEVICES

A recommended device of this type (Reference 8) would be an oriented, inflatable corner reflector. A hemispherical array of inflatable corner reflectors would eliminate the requirements for orientation. These devices would utilize the skin track mode of the LEM rendezvous radar in order to reflect sufficient RF energy, they would be large enough so that, if properly coated or pigmented, they would be visible to the astronauts during the descent phase.

C. ACTIVE RF DEVICES

A transponder at the landing site would operate with the primary transponder mode of the LEM rendezvous radar. The signal strength would be considerably greater than that of an RF reflector (see Reference 7). Such devices could be built either independent of Surveyor, requiring separate power supply and thermal control, or integrated with Surveyor and requiring an appreciable spacecraft survival time to support the transponder.

SECTION IV

COMPARISON OF LANDING AIDS

The utility of a landing aid is measured by how accurately the LEM can be expected to home-in to it. Additional value may be assigned to its use for improving the knowledge of the landed Surveyor location during lunar orbit. The cost of a landing aid is measured by its impact on the Surveyor spacecraft and may be expressed in terms of required payload weight, development time, and changes in the spacecraft from the present design.

Additional consideration is being given within the Apollo Project to the use of the rendezvous radar to assist in nulling LEM lateral touchdown velocity. The effect which the choice of a landing aid has on this function must therefore be evaluated. The lunar reflectance expected is such that the reflections from the lunar surface itself could be used to measure the horizontal velocity. If the reflectivity of the lunar surface in the vicinity of the Surveyor spacecraft were so low that surface reflections provided an inadequate signal, the spacecraft itself, or an aluminized visual landing aid, could serve as a reflector. In that case, signal-to-clutter ratio would not be of any concern. Therefore, this function, if established as an Apollo requirement, is quite insensitive to the choice of a landing aid.

If an optical tracker were to replace the rendezvous radar, angle tracking of the landing aid or the Surveyor would allow horizontal velocity to be determined.

Table 1 lists the characteristics of the different types of landing aids. Both cost and utility evaluations are presented.

Table 1. Characteristics of Proposed LEM Landing Aids

Type of Landing Aid	(1) Expected CEP (feet)	Use by LEM	Use in Lunar Orbit	Estimated weight (lb)	Estimated Development Time (mo.)	Surveyor Design Requirements
Visual	(2) 100 - 200	Must be acquired by astronauts at 8 n. mi slant range angle data only	Angle data if it can be seen	10 - 15	12	Minimum change. May require deployment mechanism.
Passive RF	100	(3) Acquisition must be at 20 n. mi slant range range, rate, and angle data	Of no use	25 - 35	12 - 18	Could accommodate within payload envelope. May require deployment mechanism.
Surveyor Independent Transponder	100	Same as passive RF but returns stronger signal	Range, range rate, and angle data	45 - 85	24	(4) Would be difficult to accommodate within payload envelope.
Surveyor Dependent Transponder	100	Same as above	Same as above	20 - 50	24	Requires development of alternate power supply; i. e., RTG, since present battery system is limiting factor in survival capabilities.
<p>(1) All CEP's pertain to reaching hover point. Astronauts will "fly" from there as required and should be able to do as well as a helicopter pilot can.</p> <p>(2) Assuming that LEM has a Landing Point Designator and that multiple site designations are possible.</p> <p>(3) Acquisition at 20 n. mi slant range is required to ensure that the landing aid is in the main lobe with 99 percent probability.</p> <p>(4) Development of RTG for both power and heating would be required for this device.</p>						

SECTION V

SUMMARY

Table 1 shows that any of the proposed devices would allow a LEM to land at a pre-determined site with great accuracy. The last three columns in the table indicate some of the problems associated with each device. It is apparent that the heavier, more sophisticated type of landing aid is the most useful, both in lunar orbit and in the LEM descent phase. However, there appears to be no possibility that active transponders, beacons, or passive radar reflectors could be carried by Surveyor because of their weight and required development problems.

Visual devices then are left by a process of elimination. Though no preliminary design is developed at this date, a decision to use such a device on the earliest follow-on Surveyor missions must be made soon if it is to be implemented. The simplest possible devices could be developed most easily for the early follow-on Surveyors. These earliest missions are the ones which might very well be required to interact with Apollo or Lunar Orbiter. Later missions might require developing alternate devices.

In addition to selecting landing aid types, a policy decision on where to land Surveyors carrying landing aids must be made. Depending on Apollo landing capability, an optimum deployment scheme should be developed such that the landing aid capability is used most effectively.

SECTION VI

RECOMMENDATIONS

The Working Group recommends that two contracts be funded. These contracts are to require performance of the work detailed in the two work statements given in Subsections A and B of this Section. The work requested in Subsection A, providing for the development of a landing aid to be carried on the Surveyor spacecraft, should be monitored by JPL. The work requested in Subsection B, the simulation of the LEM astronauts' visual capabilities during lunar descent, should be monitored by MSC. These two contracts should be carried out independently.

It is also recommended that MSC and MIT/IL continue their efforts on designing optimum trajectories and guidance capabilities for using the landing aid which is being developed.

The Working Group shall continue to monitor the progress being made until a useful landing aid is built.

A. LANDING AID DEVELOPMENT

The following work statement is recommended for implementation:

ARTICLE 1 STATEMENT OF WORK

- (a) The Contractor shall perform the effort set forth below in Phase I and after its successful completion thereof, Phase II as shown:

PHASE I - FEASIBILITY STUDY

- (1) Conduct a feasibility study of an Apollo Landing Aid (ALA) suitable for delivery to the lunar surface by a Surveyor spacecraft. If feasible, a development effort leading to a prototype will be initiated. The landing aid shall be a device which is visible from the Apollo Lunar Excursion Model (LEM) and/or other spacecraft. The ALA shall be capable of being ejected to a separated distance from the landed Surveyor spacecraft of 50 to 100 ft, and then self-erected. The ALA shall retain its optical and shape characteristics for three years on the lunar surface.

- (i) The functional requirements for the ALA are:

- A. Visual characteristics shall be investigated for geometrical shapes which shall include but not necessarily be limited to the following three configurations:

1. Spherical Specular

The surface of the specular sphere shall reflect at least 85 percent of the incident solar flux in wave length range of .400 to .700 microns. Due to the nature of specular surfaces, the spherical shape of the device will be maintained during the operational life of the landing aid, such that the intensity of light reflected from the sphere does not vary more than 20 percent when viewed from any direction.

2. Spherical Diffuse

The surface of the diffuse sphere shall closely approximate a Lambert surface. The reflecting efficiency (i. e. ratio of total reflected light to total incident light) for solar illumination will be at least 80 percent in the wave length range of .400 to .700 microns.

3. Flat Disk

The surface of the flat disk shall be diffuse and closely approximate a Lambert surface. The reflecting efficiency will be the same as stated in 2.

Any other configuration should have reflecting efficiency as stated in 2. as seen from a range of look angles ranging from 10 to 90 deg below horizontal.

- B. Stability on lunar surface shall be such that the landing aid shall be stable once located on the lunar surface. The maximum slope expected would be 15 deg.

(ii) The ALA design constraints and interface with the spacecraft are:

- A. The weight of the entire ALA systems appropriate to each weight category including the collapsed device, enclosure, ejecting and erecting equipment and any associated electrical equipment shall be considered to be approximately 10 lb, 15 lb, 20 lb, and 25 lb.
- B. The enclosure holding the ALA in its stowed position shall have a volume no greater than one cubic foot.
- C. An unobstructed ejection path above a horizontal baseline exists.
- D. Deployment shall be such that:
 - 1. The separating impulse, if any, shall not exceed 15 slug ft/sec.
 - 2. The separating force, if any, shall not exceed 1,250 lb.

- E. Compatibility will be required for three year survival at 0 deg latitude, 0 deg longitude on the lunar surface as defined by NASA Environment and Physical Standards for the Apollo Program, NASA M-DE 8020.008B SE 015-001-1.
 - F. The ALA shall not in any way contaminate the optical, temperature control, or other surfaces of the Surveyor spacecraft during its mission including the landing aid deployment.
 - G. The prime method of deployment will be by command from the spacecraft. At least one electrical command link will be available to initiate deployment.
 - H. ALA design shall be compatible with JPL Type-Approval Specifications, to be provided.
- (iii) In the performance of this effort:
- A. Study the material durability in light of the required survival on the lunar surface.
 - B. Study the material capability for erection and rigidization.
 - C. Investigate the particular constraints, if any, which impose design limitations and evaluate the required value of that constraint which would allow the design to be met.
 - D. Consider and advise JPL of the effect of adding the following two functional requirements to Paragraph (a)(1)(i).
 - 1. An automatic backup deployment mechanism to operate after a minimum time of 14 days.
 - 2. A directional control deployment which will allow some degree of placement of the ALA.

PHASE II - DEVELOPMENT STUDY

- (1) Conduct a developmental study of the ALA predicated on the result obtained in Phase I of the Contract. In the performance of this effort the Contractor shall:
 - (i) Design, develop, fabricate, and assemble demonstration models of the ALA to demonstrate their performance capabilities highlighting ejection and erection mechanisms.
 - (ii) Provide design documentation of the prototype ALA for JPL approval.
 - (iii) After JPL approval of the design, fabricate, assemble, and functionally test the prototype ALA.

PHASE III - FLIGHT ALA DEVELOPMENT

- (1) After successful completion of Phase II, JPL reserves the right to negotiate with the Contractor the development of flight model ALA's.

PHASE IV - DOCUMENTATION

- (1) For Phase I provide:
 - (i) One (1) vellum and five (5) copies of an informal letter type monthly technical progress report setting forth as a minimum:
 - A. Progress previous month.
 - B. Problems encountered and how they were resolved.
 - C. Percent completion planned vs actual.
 - D. Action items.
 - (ii) One (1) vellum of a monthly cost report on JPL Form 0330 with a graphic illustration of planned vs actual expenditures to date.
 - (iii) Oral report midway through the phase presented by the Contractor for JPL.
 - (iv) One (1) vellum and twenty (20) copies of a final report.

(2) For Phase II provide:

- (i) One (1) vellum and five (5) copies of an informal letter type monthly technical progress report setting forth as a minimum:
 - A. Progress previous month.
 - B. Problems encountered and how they were resolved.
 - C. Percent completion planned vs actual.
 - D. Action items.
- (ii) One (1) vellum of a monthly cost report on JPL Form 0330 with a graphic illustration of planned vs actual expenditures to date.
- (iii) One (1) copy of all specifications, drawings, etc., generated by the Contractor in Phase II.
- (iv) Oral report midway through the phase presented by the Contractor for JPL.
- (v) One (1) vellum and twenty (20) copies of a final report.

ARTICLE 2 DELIVERY OR PERFORMANCE SCHEDULE

- (a) Except as otherwise provided in this Contract, the point of inspection, acceptance and delivery of all supplies deliverable under this Contract shall be the Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, California. All such supplies shall be packaged, packed, boxed, or crated in such a manner as to ensure safe delivery and shall be shipped prepaid to JPL.
- (b) The Contractor shall furnish and deliver the supplies and perform the services required by ARTICLE 1, STATEMENT OF WORK, in accordance with the following schedule:

PHASE IAFTER CONTRACT GO AHEAD

- | | |
|---------------------------------------|--------------------|
| (1) Study Completion | Three (3) months |
| (2) Monthly Progress and Cost Reports | 15th of each month |
| (3) Oral Report | Six (6) weeks |
| (4) Final Report | Four (4) months |

PHASE II

- | | | |
|-----|--|---|
| (1) | Demonstration ALA | One (1) month after JPL approval of Phase I |
| (2) | Prototype Documentation for JPL Approval | Two (2) months |
| (3) | Prototype ALA | Six (6) months |
| (4) | Monthly Progress and Cost Reports | 15th of each month |
| (5) | Oral Report | Three (3) months |
| (6) | Final Report | Seven (7) months |

B. VISIBILITY SIMULATION

The following work statement calls for the minimum effort required to allow a visual landing aid to be evaluated. All effects due to LEM construction, contaminating deposits on LEM windows, astronauts' faceplates or goggles, physical condition of the astronauts, and other degrading conditions have been omitted. The effects of all those degrading conditions must be evaluated either independently or in conjunction with the work recommended below:

STATEMENT OF WORK

1.0 Purpose

The purpose of this study is to determine the required size of a passive visual landing aid in order for it to be acquired by the unaided eyes of the astronauts in the Lunar Excursion Module (LEM) under ideal viewing conditions during the final approach phase of the powered landing maneuver. Such an aid will be carried to the Moon by Surveyor and used to mark a site suitable for a manned Apollo landing.

2.0 Required Simulation

A landing aid visibility simulation shall be made under controlled conditions with a simulated lunar background obtained by use of a lunar terrain model. The principal parameters to be investigated are probability of acquisition and time of acquisition as a function of slant range, lunar lighting conditions, and size of the landing aid.

2.1 The probability of acquisition is desired between the range of 0.90 and 0.99 for maximum acquisition times of five, ten, and twenty seconds.

2.2 Independent results shall be obtained for three types of landing aids. The characteristics of each type shall be simulated as faithfully as possible, including shadows and variations in luminance over the surface of the aid. Scaling of the aids is acceptable if appropriate scaling of all other parameters is performed and justified.

2.3 The slant range to the landing aid varies from 10 n miles to 4 n miles. The LEM approach trajectory is approximately 13 deg below horizontal, directly toward the center of the region where the landing aid is located.

2.4 The location of the landing aid relative to the LEM is known to a 1σ accuracy of 3600 ft on the lunar surface parallel to the direction of travel, and 1400 ft perpendicular. The placement of the landing aid during the simulations shall be gaussian with these standard deviations. The center of the distribution can be determined by the astronaut to within an angle of 1 deg (1σ).

3.0 Description of the Landing Aids

3.1 Spherical Specular Landing Aid

- 1) The surface shall reflect 85 percent of the incident illumination in the range .400 to .700 micron, and the intensity of the reflected light will be isotropic to within ± 20 percent.
- 2) The marker size on the lunar surface will be limited to between 5 and 25 ft diameter.

3.2 Spherical Diffuse Landing Aid

- 1) The surface shall reflect 80 percent of the incident radiation in the wavelength region of .4 to .7 micron. Each element of the surface shall approximate a Lambert reflector.
- 2) The marker size on the lunar surface will be limited to between 5 and 25 ft diameter.

3.3 Flat Disk Landing Aid

- 1) The surface shall reflect 80 percent of the incident illumination in the wavelength region .400 to .700 microns. The surface will closely approximate a Lambert surface.
- 2) The marker size will be limited to between 5 and 50 ft diameter.

4.0 Lunar Lighting Conditions

The following items are essential considerations to the simulations.

4.1 Photometry

The photometry of the lunar surface shall be as described for marial surfaces in "Natural Environment and Physical Standards for the Apollo Program," NASA M-D E 8020.008B, SE 015-001-1.

4.2 Surface Characteristics

The surface used in the simulations shall resemble in surface roughness, the Moon as measured from low altitude Ranger Photographs.

4.3 Range of Sun Angles

Simulations shall be conducted for Sun angles between 10 deg and 50 deg above the horizon. Azimuths of up to 40 deg on one side of the trajectory plane shall be considered for the Sun both behind and in front of the observer.

4.4 Photometric Measurements

All photometric measurements shall be reported in complete detail, including calibration of the instruments. Data shall be reported on the photometric properties of the simulated lunar surface and the landing aids.

5.0 Data Pertinent to the Simulations

5.1 Each observer shall be measured for static acuity. No observer shall have visual acuity worse than 20/20, corrected. Complete records shall be maintained of the performance of each observer, and significant correlations and trends shall be determined. An attempt shall be made to have the group of observers approximate the general characteristics of the astronauts.

6.0 Other Considerations

6.1 The effect of lunar surface albedos which vary by 50 percent from that specified in the "Natural Environment and Physical Standards for Apollo" shall be studied.

6.2 The following effects shall be ignored for the purpose of this study:

- a) LEM Window
- b) Astronaut's goggles
- c) Rocket plumes
- d) Vibration
- e) Fatigue of astronaut
- f) Acceleration
- g) LEM cabin environment

7.0 Schedule

7.1 This study is to be completed within 3 months. A final written report and an oral presentation will be presented at this time.

7.2 A mid-term oral presentation shall be presented after six weeks effort. It is essential at this report to present sufficient analyzed data to allow a determination that the size of landing aids which are being considered are reasonable to perform the objective.

SECTION VII

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9. "Radar Markers for Surveyor", E. N. Shipley, Bellcomm, Inc. TR 64-211-1 dated October 21, 1964.

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